12 PRTS

10/522334

WO 2004/013427

PCT/JP2003/008796

Rec'd PCT/PTO 25 JAN 2005

DESCRIPTION

SOUND-ABSORBING STRUCTURE AND SOUND-ABSORBING UNIT

TECHNICAL FIELD

The present invention relates to sound-absorbing structure and sound-absorbing unit that absorb a grating noise. More specifically, the present invention relates to sound-absorbing structure and sound-absorbing unit with partition plates that divide the air layer behind a sound-absorbing material.

BACKGROUND ART

Sound-absorbing unit with partition plates, which divide the air layer between a sound-absorbing material and a base plate into a plurality of lattice 'cells', is known, as disclosed in JP,11-161282,A. In this sound-absorbing unit, the height of the air layer in the sound wave incident direction is set to one-fourth of the wavelength of a target sound. This enables the energy of the sound wave to be absorbed efficiently. Thus, according to the conventional sound-absorbing unit, a sound absorbing coefficient for a particular frequency component is improved, and it becomes possible to reduce the weight of the sound-absorbing unit while maintaining its high sound absorbing coefficient.

Generally, sound-absorbing unit is positioned such that it surrounds the sound source. In the space where the sound-absorbing unit is placed, there are a variety of sound waves. For example, there are sound waves incident indirectly into sound-absorbing unit via reflections at the structures around the sound source as

well as the ones incident directly into sound-absorbing unit from the sound source. Thus, the variety of incident directions becomes wide. Especially in a closed space such as the engine room of a vehicle and a cabin, etc., the variety of the traveling directions of sound waves is quite wide because the reflections of the sound waves occur repeatedly. For this reason, in order to improve its overall sound-absorbing performance, sound-absorbing unit is required to achieve a good sound-absorbing performance for the sound waves with a variety of incident directions.

Further, sound-absorbing unit is required to have a structure or performance suitable for its installation place. For example, in the case of being installed in a cabin, the sound-absorbing unit should have a sound-absorbing configuration on its inner side suitable for absorbing the grating noise in the cabin, while it should have a sound-insulating configuration on its outer side suitable for insulating the noise transmitted into the cabin from outside. Furthermore, if sound-absorbing unit additionally serves as an interior component, it is required to have sufficient strength and durability as an interior component.

In particular, the above-mentioned conventional sound-absorbing unit has defects in terms of sound-insulating characteristics. In such cell-type sound-absorbing unit, sound waves are likely to be transmitted into the cabin from outside because the partition plates that define cells don't have a function of blocking the sound waves passing through the cells.

DISCLOSURE OF INVENTION

It is a general object of the present invention

to provide sound-absorbing structure and sound-absorbing unit that have a high sound-absorbing capability as well as a high sound-insulating capability and that can provide an efficient sound-absorbing effect centered on a particular target frequency.

In order to achieve the above-mentioned objects, according to one aspect of the present invention a sound-absorbing structure, comprising: a substantially flat support base; a substantially flat sound-absorbing material arranged substantially parallel to the support base; and a corrugated partition plate interposed between the support base and the sound-absorbing material, the corrugated partition plate having upper antinode portions opposed to the sound-absorbing material and lower antinode portions opposed to the support base; wherein the lower antinode portions of the corrugated partition plate are at least partially separated from the support base.

In the above-mentioned aspect of the present invention, between the sound-absorbing material and the support base is provided the corrugated partition plate. Thus, the sound waves coming from the support base's side lose a large amount of energy thereof when they pass through the corrugated partition plate. Further, there is a gap (separation) between the lower antinode portions of the corrugated partition plate and the support base. Thus, the vibration of the support base cannot be transmitted to the corrugated partition plate directly. This improves the sound-insulating effect of the sound-absorbing structure without interposing a conventional acoustic insulating material with high-destiny/thickness/weight between the corrugated partition plate and the support base.

Additionally, the lower antinode portions of the

corrugated partition plate may be supported via an elastic element. This effectively lessens the transmission of the vibration of the support base to the corrugated partition plate. Additionally, the lower antinode portions of the corrugated partition plate may be supported by low-vibration portions of the support base, such as reinforced portions with strengthening ribs and the like. This also lessens the transmission of the vibration from the support base to the corrugated partition plate. As a result, it becomes possible to improve the sound-insulating effect of the sound-absorbing structure without interposing a conventional acoustic insulating material with high-destiny/thickness/weight between the corrugated partition plate and the support base.

According to another aspect of the present invention a sound-absorbing unit comprising: a corrugated partition plate having a first side and a second side opposite to the first side; a substantially flat sound-absorbing material provided on the first side of the corrugated partition plate; and at least one second partition plate configured to partition air spaces defined between the sound-absorbing material and the corrugated partition plate.

In the above-mentioned aspect, the second partition plate partitions the air spaces that extend in a first direction, in which antinode portions of the corrugated partition plate extend, between the corrugated partition plate and the sound-absorbing material. By virtue of the second partition plate, the entry of the sound waves in a slanting direction at an angle to the first direction can be limited, which enables the concentration of the sound-absorbing effect on a desired frequency band. As a result, it becomes possible to keep

the overall sound-absorbing effect high even if the sound-absorbing unit is placed in such a sound field where the sound waves may enter into the sound-absorbing unit from various directions. Furthermore, by virtue of the second partition plate, the in-plane rigidity of the corrugated partition plate increases and thus the potential for deformation of the corrugated partition plate decreases. Thus, it becomes possible to give the sound-absorbing unit the required strength as an interior component.

Additionally, the second partition plate may extend in a direction substantially perpendicular to the first direction in which antinode portions of the corrugated partition plate extend.

Additionally, sound-absorbing materials may be provided respectively on both sides of the corrugated partition plate. With this arrangement, it becomes possible to absorb the sound waves incoming from various directions on both sides of the sound-absorbing unit and to further improve the overall sound-absorbing effect of the sound-absorbing unit.

Additionally, the second partition plate may be configured to partition the air portions only on the first side of the corrugated partition plate. With this arrangement, miniaturization of the second partition plate and weight reduction are enabled while maintaining the above-mentioned high sound-absorbing effect on one side.

Additionally, the corrugated partition plate may include a wave pattern whose phase and/or amplitude is varied at a boundary between the corrugated partition plate and the second partition plate. This arrangement allows the sound-absorbing unit to deliver the sound-absorbing performance over a wide frequency band and increases an out-plane rigidity and thus durability of the

second partition plate.

Additionally, the corrugated partition plate may include a sine wave pattern and/or a rectangular wave pattern. The corrugated partition plate with a sine wave pattern among others has high stiffness and thus leads to improvement in the sound-insulating effect. Furthermore, with the corrugated partition plate with sine wave pattern among others, the entry of the sound waves into the air spaces can be promoted effectively since the acoustic impedance changes gradually.

Additionally, the corrugated partition plate may include wave patterns with different frequencies and/or different amplitudes. With this arrangement, it becomes possible to gain a sound-absorbing effect over a wide frequency band and optimize the sound-absorbing effect according to the characteristics of the sound field in the vicinity of the sound-absorbing unit.

According to another aspect of the present invention a sound-absorbing unit is provided that includes a partition plate having recesses; and a sound-absorbing material which covers air portions defined inside the recesses.

In the above-mentioned aspect of the present invention, the partition plate having recesses can be formed from a sheet material. This leads to a reduction in parts count for the sound-absorbing unit and increases productivity for manufacturing the sound-absorbing unit while maintaining the above-mentioned high sound-absorbing/insulating effect. Further, this arrangement can limit the entry angle of the sound waves in a slanting direction with respect to the sound-absorbing unit. As a result, the sound waves incident from various directions can be absorbed efficiently and the sound absorbing effect

is not distributed over a wide frequency range other than the target frequency range.

Additionally, each recess may have a cross-sectional area that gradually varies with the depth of the recess. A partition plate with such recesses has a high stiffness against loads applied from various directions. This arrangement leads to improvement in the sound-insulating effect of the partition plate as well as in the durability of the sound-absorbing unit. Furthermore, since the acoustic impedance changes gradually inside the recesses, the entry of the sound waves into the recesses can be promoted effectively.

In the above-mentioned aspects of the present invention, the thickness of air portions behind the sound-absorbing material may be set to odd multiples of one-fourth of the wavelength of sound waves of target frequencies. With this arrangement, the sound waves input in air portions can be absorbed efficiently, because the sound waves pass through the sound-absorbing material at maximum particle velocity.

Other objects, features and advantages of the present invention will become more apparent from the following detailed description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a conceptual rendering for illustrating a state of sound waves incoming in a perpendicular direction with respect to the sound-absorbing unit.

Fig. 1B is a conceptual rendering for illustrating a state of sound waves incoming in a slanting direction with respect to the sound-absorbing unit.

Fig. 1C is a conceptual rendering for illustrating a state of sound waves in the case of the sound-absorbing unit with partition plates.

Fig. 2A is a diagram for showing a sound-absorbing effect centered on a particular frequency.

Fig. 2B is a diagram for showing a sound-absorbing effect spreading over a wide frequency band depending on the cell width W.

Fig. 3A is a cross-sectional view of a sound-absorbing unit according to the first embodiment of the present invention.

Fig. 3B is a perspective view of the partition plate of the sound-absorbing unit of the first embodiment.

Figs. 4A-4C are diagrams for showing variations in placing the partition plate of the sound-absorbing unit.

Figs. 5A-5D are diagrams for showing alternative embodiments of the present invention.

Fig. 6A is a cross-sectional view of a sound-absorbing unit according to the second embodiment of the present invention.

Fig. 6B is a perspective view of the partition plates of the sound-absorbing unit of the second embodiment.

Fig. 7 is a cross-sectional view for showing a variant of the sound-absorbing unit according to the present invention.

Figs. 8A and 8B are cross-sectional views of the sound-absorbing unit for showing alternative embodiments of the present invention.

Fig. 9A is a perspective view of a sound-absorbing unit according to an alternative embodiment.

Fig. 9B is a cross-sectional view of the sound-absorbing unit of Fig. 9A.

Figs. 10A-10C are diagrams for showing variations of a wave pattern of the corrugated partition plate.

Fig. 11A is a cross-sectional view of a sound-absorbing unit according to the third embodiment of the present invention.

Fig. 11B is a perspective view of the partition plate of the sound-absorbing unit of the third embodiment.

Fig. 12A is a cross-sectional view of the partition plate according to an alternative embodiment taken on the line A-A or B-B of Fig. 12B.

Fig. 12B is a perspective view of the sound-absorbing unit of the alternative embodiment of Fig. 12A.

BEST MODE FOR CARRYING OUT THE INVENITON

Hereafter, the preferred embodiments according to the present invention are explained with reference to the drawings.

First, a fundamental principle on which the present invention is based is described prior to the description of sound-absorbing unit according to the present invention. Figs. 1A-1C are conceptual renderings for illustrating a state of sound waves incident on a sound-absorbing material 30 from above, with an air layer 32 being between a support base 34 and the sound-absorbing material 30.

Referring to Fig. 1A, if the sound waves with wavelength λ enter perpendicularly with respect to the support base 34, standing-waves are formed by a combination of incident waves and reflected waves. The standing-waves have antinodes at the points that are separated from the support base 34 by distances of odd multiples of one-fourth of the wavelength λ. The particle velocity of sound waves

becomes its maximum at the antinodes. Thus, if the sound-absorbing material 30 is located at the point where the particle velocity of sound waves becomes a maximum, the sound-absorbing efficiency will be maximized because the sound waves pass through the sound-absorbing material 30 at their highest energy level. In other words, setting the thickness of the air layer 32 between the support base 34 and the sound-absorbing material 30 to odd multiples of one-fourth of the wavelength λ of the target sound waves to be absorbed can significantly increase the sound absorbing coefficient around the frequency of the target sound waves.

On the other hand, if the sound waves enter in a slanting direction, as shown in Fig. 1B, the above-mentioned standing-waves aren't formed. Thus, in a sound field in which there are a variety of incident directions of sound waves, such as in a sound field inside the cabin of a vehicle, the sound absorbing effect will be distributed over a wide frequency range other than the target frequency range, resulting in a decrease in the overall sound absorbing capability. In addition, since the sound absorbing effect is distributed over wide frequency range and the sound pressure level is reduced universally over the wide frequency range, the sensory effect as perceived by a human cannot be improved.

One approach to solve this problem is to divide the air layer 32 into a plurality of cells by placing partition plates 36 that limit the incidence of sound waves in slanting directions, as shown in Fig. 1C. In this case, the above-mentioned standing-waves are formed even in a sound field with sound waves of a variety of incident directions. The distance W1 defines the range of incident angles of sound waves that can enter into cells. Thus, by determining the distance W1 as desired, for example, it

becomes possible to concentrate the sound-absorbing effect into the area around the target frequency, as shown in Fig. 2A, or to distribute the sound-absorbing effect over the desired frequency band centering on the target frequency, as shown in Fig. 2B.

According to the one aspect of the present invention described hereafter, a sound-absorbing unit is provided that is equipped with a sound-absorbing/insulating structure with increased sound-absorbing/insulating capability based on the above-mentioned principle.

Fig. 3A is a cross-sectional view of a sound-absorbing unit according to the first embodiment of the present invention. Fig. 3B is a perspective view of the partition plate of the sound-absorbing unit of this embodiment. The sound-absorbing unit 50 consists of a sound-absorbing material 51 and a partition plate 52.

The partition plate 52 according to the first embodiment has a wave-shaped cross-section with the upper and lower antinode portions 52a, 52b, respectively, extending substantially in parallel with each other in a constant direction. Although the corrugated partition plate 52 is made of stamped aluminum plate in terms of weight reduction, it can be made of hard resin such as polypropylene-based resin or steel, etc.

The pitch W1 between the neighboring upper antinode portions 52a may be determined, based on the above-mentioned principle, considering the target frequency band and the characteristics of the sound field around the sound-absorbing unit 50. It is noted that each of the antinode portions 52a, 52b of the corrugated partition plate 52 don't necessarily extend in parallel spaced at regular intervals, and don't necessarily extend linearly. For example, the antinode portions 52a, 52b may be curved.

Accordingly, the pitches W1 may be set differently between every two neighboring antinode portions 52a, 52b, and/or the pitch W1 may be varied along the direction of the antinode portions 52a, 52b.

The sound-absorbing material 51 is made of processed metal fiber such as aluminum fiber or mineral fiber such as glass wool and rock wool, etc. However, sound-absorbing material 51 can be made of synthetic resin foam such as polystyrene-based resin and polyethylene-based resin, etc., or flexible material such as urethane and rubber, or porous material.

The sound-absorbing unit 50 of this embodiment is placed on a support base 80 such as a body panel of a vehicle with its sound-absorbing material 51 facing toward the space where there are sound waves to be absorbed. With this placement, the first air layers 70 are defined between the sound-absorbing material 51 and the corrugated partition plate 52, while the second air layers 75 are defined between the support base 80 and the corrugated partition plate 52. In other words, the corrugated partition plate 52 is provided such that it divides the air layer between the support base 80 and the sound-absorbing material 51 into the first air layers 70 on the side of the sound-absorbing material 51 and the second air layers 75 on the side of the support base 80. As a result, the above-mentioned standing-waves are formed inside the first and second air layers 70, 75, respectively, when the sound waves enter from both sides of the sound-absorbing unit 50.

Concerning the placement procedure of the sound-absorbing unit 50, it is noted that you may attach the sound-absorbing material 51 to the corrugated partition plate 52 by means of an adhesive or screws, etc., and then place this combination on the support base 80.

Alternatively, you may set the sound-absorbing material 51 so as to form the air layer between the sound-absorbing material 51 and the support base 80 and then position the corrugated partition plate 52 between them such that it can divide the air layer. The means for supporting the corrugated partition plate 52 may be varied depending on the place where sound-absorbing unit 50 is located. For example, you may simply place it on the support base 80 or fix it to the support base 80 by an adhesive, clips, screws, etc.

The thickness D (depth) of the first air layer 70 is set to be one-fourth of the wavelength λ of the target sound waves that should be absorbed according to the above-mentioned principle (see Figs. 1A and 1C). This enables the sound waves entering from the sound-absorbing material's side to be absorbed efficiently, because the sound waves pass through the sound-absorbing material 51 at maximum particle velocity.

It is noted that, in the case of the target frequency band being wide, the thickness D may be set differently for every first air layer 70, and/or it may be varied along the direction of the antinode portions 52a, 52b. Such a change in the thickness D of the first air layers 70 may be implemented by varying the amplitude of the corrugated partition plate 52 or by forming projections and depressions on the sound-absorbing material 51. In the former case, the amplitude of the corrugated partition plate 52 may be determined according to the contour of the surface of the support base 80, such as step height, in order to stabilize the sound-absorbing unit 50 in its place.

According to this embodiment, the sound-absorbing material 51 contacts the corrugated partition plate 52 (i.e. upper antinode portions 52a) by line contact. Therefore,

the first air layers 70 are defined substantially by all the area behind the sound-absorbing material 51. This enables the sound-absorbing material 51 to exert the high sound-absorbing effect substantially all over its surface area. It is noted that the neighboring first air layers 70 are not necessarily isolated from each other, so some first air layers 70 may be in communication with their neighboring first air layers 70. In other words, even if the sound-absorbing material 51 doesn't contact the upper antinode portions 52a of the corrugated partition plate 52 and there is a certain clearance between them, the sound-absorbing material 51 can exert the high sound-absorbing effect substantially all over the surface area thereof.

By the way, in order to further improve the above-mentioned high sound-absorbing performance, it is important to promote the entry of the sound waves into the first air layers 70. For example, with such lattice-type cells as shown in Fig. 1C, the sound waves cannot travel smoothly inside the cell because the cross-sectional area (the area seen from above) of each cell is constant along the thickness direction.

To the contrary, according to this embodiment, the first air layers 70 have a cross-sectional area that gradually increases from the bottom side (support base's side) to the opening side. This enables the gradual change of the acoustic impedance, that is, a smooth sound wave propagation inside the first air layers 70. With this arrangement, it is possible to input the sound waves into the first air layers 70 efficiently and thus to improve the sound-absorbing performance of the sound-absorbing unit.

Next, the sound-insulating performance of the sound-absorbing unit 50 of this embodiment is described in detail.

Generally, a sound-absorbing unit is placed in the space around the sound source such as an engine or in a cabin. Especially, in the case of the sound-absorbing unit being placed inside a space such as a cabin, theater room, etc., the most effective approach for improving the quietness of the space is to block the sound incoming from the outside of the space. Thus, for example, the sound-absorbing unit in a cabin is required to deliver a high sound-insulating performance against the external noise that may enter the cabin as well as the high sound-absorbing performance against the target sound inside the cabin. That is, the sound-absorbing unit is required to have a high sound-insulating capability on the side opposed to a body panel (support base 80) and high sound-absorbing capability on its cabin side.

According to the sound-absorbing unit 50 of this embodiment, the corrugated partition plate 52 can block the external noise incoming from the side opposed to the support base 80. That is, the external noise incoming from behind of the sound-absorbing unit 50 lose a significant part of their energy at the time of transmitting through the corrugated partition plate 52 before reaching the sound-absorbing material 51. Furthermore, the corrugated partition plate 52 has a high stiffness due to its corrugated cross-section. This means that sound transmission loss is large and the intensity level of a sound will be reduced significantly at the time of the transmission through the corrugated partition plate 52. Thus, the sound-absorbing unit 50 of this embodiment can implement a high sound-insulating performance for an external noise.

Next, the improved placement of the sound-absorbing unit 50 of this embodiment, which enables further

improvement in a sound-insulating capability, is described.

Referring to Fig. 4A, the sound-absorbing unit 50 is placed with its corrugated partition plate 52 being separated from the support base 80. In this placed state of the sound-absorbing unit 50, the lower antinode portions 52b of the corrugated partition plate 52 are separated from the support base 80 by the gap Δ. This prevents the vibration of the support base 80 from being transmitted to the corrugated partition plate 52 directly and reduces the amount of transmitted sound at the corrugated partition plate 52. Therefore, the sound-absorbing unit 50 of this embodiment is suitable for being placed on the support base 80 that is easy to vibrate, such as a body panel.

It is noted that the corrugated partition plate 52 may be supported in a vibration-free manner by separate support members (not shown) with a high stiffness. In this case, an additional sound-absorbing material may be attached to the corrugated partition plate 52 on its side opposed to the support base 80 such that the additional sound-absorbing material is separated from the support base 80. This enables the sound waves incoming from behind (i.e. from the side opposed to the support base 80) to be absorbed effectively.

Alternatively, in anothre placed state of the sound-absorbing unit 50, the corrugated partition plate 52 may be supported locally by the support base 80, as shown in Fig. 4B. More specifically, parts of lower antinode portions 52b of the corrugated partition plate 52, or some of the lower antinode portions 52b may be mounted on the support base 80. In this case, the contact portions of the support base 80 are preferably low-vibration portions or vibration-free portions, such as portions reinforced with ribs or stiffeners, portions corresponding to nodes of

possible vibration modes of the support base 80, etc.

Alternatively, in yet another placed state of the sound-absorbing unit 50, the corrugated partition plate 52 may be supported by the support base 80 via the elastic elements 90 made of a flexible material and having a low elasticity characteristic, as shown in Fig. 4C. Preferably, the elastic elements 90 are located locally according to the lower antinode portions 52b of the corrugated partition plate 52. That is, the elastic elements 90 are positioned so as to be associated with parts of a lower antinode portions 52b of the corrugated partition plate 52, or some of the lower antinode portions 52b. In this case, at the points where the elastic elements 90 aren't provided, the lower antinode portions 52b are separated from the support base 80, as in the example shown in Fig. 4B. In this way the direct transmission of the vibration at these points can be avoided.

According to the sound-absorbing unit discussed with reference to Figs. 4A-4C, it becomes possible to significantly reduce the amount of sound transmitted at the contact portions between the corrugated partition plate 52 and the support base 80 without placing a conventional acoustic insulating material with high-destiny/thickness/weight between them. This also leads to a weight reduction of the sound-absorbing unit.

To summarize, the sound-absorbing unit 50 of the first embodiment can efficiently absorb the target noise by its sound-absorbing structure and can efficiently prevent the entry of noise into the space (e.g., a cabin) and thus can reduce the noise to be absorbed by the sound-absorbing material 51.

It is noted that in the above-mentioned embodiment the corrugated partition plate 52 has a wave-

shaped cross-section, however, the present invention is not limited to this cross-section. For example, in an alternative embodiment shown in Fig. 5A, the corrugated partition plate 52 has a rectangular wave-shaped cross-section. In this alternative embodiment, the ratio of the sound-absorbing capability to the sound-insulating capability may be optimized using the widths of the first and second air layer 70, 75 as parameters such that these capabilities can adapt to the respective noise levels on both sides of the sound-absorbing unit. For example, in the case of placing a higher priority on a sound-absorbing capability, the width of the first air layer 70 may be set larger than that of the second air layer 75 to increase the area of the first air layer 70 behind the sound-absorbing material 51.

Further, in alternative embodiments shown in Figs. 5B-5D, the corrugated partition plate 52 has triangular, exponential horn-shaped, and dimple-shaped (egg-shaped) cross-sections, respectively. In these embodiments, the entry of the sound waves into the first air layers 70 can be promoted effectively since the acoustic impedance changes gradually inside the first air layers 70, as in the aforementioned first embodiment.

According to the second aspect of the present invention described hereafter, a sound-absorbing unit is provided which can effectively absorb the sound waves with a variety of incident angles, based on the above-mentioned principle.

Fig. 6A is a cross-sectional view of a sound-absorbing unit according to the second embodiment of the present invention. Fig. 6B is a perspective view of the partition plates of the sound-absorbing unit of this embodiment. The sound-absorbing unit 60 consists of a

sound-absorbing material 51, a partition plate 52 and second partition plates 53. The sound-absorbing material 51 and the partition plate 52 can be configured as the aforementioned embodiments (including alternative embodiments). The like components indicated by like references are the same as the aforementioned ones, unless otherwise specified.

The second partition plates 53 are substantially rectangular flat plate. The second partition plates 53 may be made of an aluminum or steel plate, as is the partition plate 52. According to this embodiment, the second partition plates 53 are placed in the direction X that is substantially perpendicular to the direction Y in which the antinode portions 52a, 52b of the corrugated partition plate 52 extend, as shown in Fig. 6B. In other words, the first and second air layers 70, 75 extending in the 'wave-streak direction' of the corrugated partition plate 52 (the direction Y in Fig. 6B) are partitioned by the second partition plates 53 that cross the antinode portions 52a, 52b. It is noted that two second partition plates 53 are shown in Fig. 6B, however, the present invention is not limited to this number. The number of the second partition plates 53 may be determined according to the overall size of the sound-absorbing unit 60.

The first and second air layers 70, 75 partitioned by the second partition plates 53 have the width W2 in the wave-streak direction Y that is determined based on the above-mentioned principle, while considering the target frequency band and the characteristics of the ambient sound field, etc. The width W2 of the first and second air layers 70, 75 may be set differently between every first and second air layer 70, 75. In this case, the second partition plates 53 may have steps in the direction

Y at the boundary between the first air layers 70 and the second air layers 75. Alternatively, the second partition plates 53 may be the sector-shaped plates matched with the cross-section of the corrugated partition plate 52. In this case, sector-shaped plates may be arranged on the surface of the corrugated partition plate 52 in a shifted manner. Further, the two neighboring second partition plates 53 don't necessarily extend in parallel with each other. So, the respective second partition plates 53 may extend in different directions.

The sound-absorbing unit 60 of this embodiment may be mounted on the support base 80 via the elastic element 90, as shown in Fig. 6A. It is noted that elastic element 90 can be a low-destiny sheet material because the corrugated partition plate 52 is equipped with the sound-insulating capability for noise coming from behind (the direction Z in Fig. 6B) as mentioned above. Alternatively, the sound-absorbing unit 60 of this embodiment may be placed so as to offer increased sound-insulating performance, as are the ones shown in Figs. 4A-4C.

Alternatively, the sound-absorbing unit 60 may be placed with both its sides exposed to an open space so that it can absorb the noise coming from both its sides, as shown in Fig. 7. In this variant, the aforementioned partition plates 52, 53 are placed between the two sound-absorbing materials 51a, 51b. This enables the noise coming from both sides of the sound-absorbing unit 60 to be absorbed efficiently.

According to the sound-absorbing unit 60 of the second embodiment, the second partition plates 53 have a function of limiting the incident angle of sound waves, as mentioned above with reference to Fig. 1C. Thus, the above-mentioned standing-waves are formed inside the sound-

absorbing unit 60, even if the sound waves enter in a slanting direction along the wave-streak direction Y. Therefore, according to the second embodiment, even if the sound-absorbing unit 60 is placed in a sound field in which there are a variety of incident directions of sound waves, the above-mentioned high sound absorbing effect is not distributed over a wide frequency range other than the target frequency range.

Furthermore, in this second embodiment, the second partition plates 53 enable in-plane rigidity (the rigidity against the load applied in the direction Z) of the corrugated partition plate 52 to increase. That is, the second partition plates 53 also have a function of preventing the corrugated partition plate 52 from deforming into a flattened structure. Thus, the sound-absorbing unit 60 is given sufficient strength that is required for an interior component. In addition, the sound-absorbing unit 60 can hold its function for a long time, without being deformed or damaged, even if it is placed where it is likely to be subjected to the load from above, such as the floor of a cabin.

Next, several variants of the above-mentioned second embodiment are described with reference to Figs. 8A and 8B.

In Fig. 8A, the second partition plates 53 which partition only the first air layer 70 are shown as indicated by shading. According to this variant, additional weight reduction of the sound-absorbing unit 60 is achieved by partitioning only one of air layers (in this example, the first air layer 70 lying on the cabin's side). The sound-absorbing unit 60 of this variant is suitable when it is required to offer the high sound-absorbing performance only on its one side.

It is noted that the second partition plates 53 may partition only a part of the air layer (in this example shown in Fig. 8A, only the upper part of first air layer 70 is partitioned). Further, it is also possible to tune the sound-absorbing/insulating capabilities by a combination with the second partition plates 53 as shown in Fig. 8B, considering noise levels on both sides of the sound-absorbing unit 60.

In the variant shown in Fig. 9A, the corrugated partition plates 52 have a wave-shaped cross-section whose phases and/or heights vary at the intersections of the corrugated partition plates 52 and one of the second partition plates 53. In other words, the second partition plates 53 are placed between the corrugated partition plates 52 with different phases and/or heights.

According to this variant, the sound-absorbing unit 60 can have a high sound-absorbing effect over a relatively wide frequency band by virtue of the difference in phases and/or heights of the corrugated partition plates 52. In addition, an out-of-plane rigidity (the rigidity against the load applied in the direction Y) of the second partition plates 53 can be increased by virtue of the difference in phases and/or heights of the corrugated partition plates 52. This increases durability of the sound-absorbing unit 60. Thus, the sound-absorbing unit 60 of this variant is suitable for being placed in a space where there are noise over a relatively wide frequency band and loads applied from various directions, such as the floor of a cabin where the sound-absorbing unit 60 is likely to be subjected to loads by legs of occupant.

Fig. 9B is a cross-sectional view of the sound-absorbing unit 60 in Fig. 9A, as viewed along direction Y. In Fig. 9B, the corrugated partition plate 52 (its cross-

section drawing is indicated by a dotted line in Fig. 9B) has its phase shifted by π and is half height with respect to those of its neighboring corrugated partition plate 52 (indicated by the solid line). It can be easily understood from Fig. 9B that the strength of the second partition plates 53 against the load in the direction Y is increased and damage to the upper portions A of second partition plates 53 can be avoided.

Similarly, the corrugated partition plate 52 (shown in Fig. 10A) may have a different pitch W1 with respect to that of its neighboring corrugated partition plate 52 as shown in Fig. 10B. Further, the pitch W1 and/or depth may vary along the direction X, as shown in Fig. 10C.

According to the third aspect of the present invention described hereafter, a sound-absorbing unit is provided which has a partition plate that can simultaneously achieve functions of the corrugated partition plate 52 and the second partition plates 53.

Fig. 11A is a cross-sectional view of a sound-absorbing unit according to the third embodiment of the present invention. Fig. 11B is a perspective view of the partition plate of the sound-absorbing unit of this embodiment. The sound-absorbing unit 70 consists of a sound-absorbing material 51 and a partition plate 54. The sound-absorbing material 51 can be configured as in the aforementioned embodiments.

The sound-absorbing unit 70 of this embodiment may be configured and placed as in the aforementioned embodiments (see Figs. 4A-4C and Fig. 7). For example, the sound-absorbing unit 70 may be mounted on the support base 80 via the elastic element 90, as shown in Fig. 11A. It is noted that elastic element 90 can be a low-destiny sheet

material because the partition plate 54 is equipped with the sound-insulating capability for noise coming from behind, as the corrugated partition plate 52 mentioned above.

According to this embodiment, the partition plate 54 is made of aluminum plate, etc. which has a plurality of recesses 54d. The partition plate 54 is provided with a sound-absorbing material 51, as in the aforementioned embodiments. The sound-absorbing material 51 and the outer surfaces of the recesses 54d define the first air layer 70. The thickness of the first air layer 70 is set to one-fourth of the wavelength λ of the target sound waves or the odd multiples of one-fourth of the wavelength λ, as in the aforementioned embodiments.

As shown in Fig. 11A and Fig. 11B, the recesses 54d have a circular cross-section (in the X-Y plane) whose radius decreases gradually toward the support base 80. The recess 54d is rotationally symmetric around the pivot axis that passes through the center of the circular cross-section. However, the present invention is not limited to this configuration. For example, the cross-section of the recess 54d may be oval, trapezoid, etc. Further, the configuration of the recess 54d may be a polygonal pyramid such as triangular pyramid and rectangular pyramid, or a truncated polygonal pyramid, or a polygonal pyramid whose top is rounded off. In Fig. 12A and Fig. 12B, truncated rectangular pyramid-shaped recesses 54d are shown.

Preferably, the recesses 54d are placed at high density so as to increase the area of the air layer (i.e. the first air layer 70) behind the sound-absorbing material 51 as much as possible. Further, the opening shape of the recess 54d (i.e. pitches W1 and W2) may be determined based on the above-mentioned principle, while considering the

target frequency band and the characteristics of the ambient sound field, etc.

According to the sound-absorbing unit 70 of the third embodiment, the sound waves incident from various directions can be absorbed efficiently and a sound absorbing effect is not distributed over a wide frequency range other than the target frequency range, as in the second embodiment. In addition, the partition plate 54 with the recesses (cells) 54d can be formed by stamping a sheet or integral foam-molding of resin. This leads to a reduction in parts count for a sound-absorbing unit and eases assembly for a sound-absorbing unit. Furthermore, the entry of the sound waves into the recesses 54d can be promoted effectively because the cross-sectional area of the recess 54d changes gradually along the direction Z and thus the acoustic impedance changes gradually inside the recesses 54d. Further, the partition plate 54 has a high rigidity against loads in every direction by virtue of the shape of the recesses 54d. This yields a high sound-insulating performance for the sound waves incident from various directions as well as a high strength for the loads applied from various directions. Thus, the sound-absorbing unit 70 of this embodiment is suitable for being placed in a space where there can be noise traveling in various directions and loads applied from various directions, such as the floor of a cabin.

The present invention is disclosed with reference to the preferred embodiment. However, it should be understood that the present invention is not limited to the above-described embodiments, and variations and modifications may be made without departing from the scope of the present invention.

For example, in the aforementioned third

embodiment, some recesses 54d may have different shapes and/or depths with respect to other recesses 54d. Further, in Fig. 11B and Fig. 12B recesses 54d formed regularly are shown, however, the positions and shapes, etc. of the respective recesses 54d may be optimized according to the sound field characteristics in the vicinity of the sound-absorbing unit.

Further, the sound-absorbing material 51 is placed on the opening side of the recesses 54d such that it covers the recesses 54d in the aforementioned third embodiment. However, the sound-absorbing material 51 may be placed on the opposite side such that it covers the bottom side of the recesses 54d. In this case, the sound-absorbing material 51 may replace the elastic elements 90 shown in Fig. 11A. With this arrangement, the sound waves entering into the second air layer 75 can be absorbed efficiently.

Further, the sound-absorbing unit in a cabin is described by way of illustration in the above-described embodiments; however, the sound-absorbing unit may be placed in an engine room, for example. Further, the sound-absorbing unit according to the present invention may act as an acoustic insulating unit used in a house (e.g., the space inside a double ceiling or floor), or a sound-proof wall disposed on a roadside. Further, the sound-absorbing unit according to the present invention is applicable to every portion of a cabin, such as a roof, a floor, a dash panel, a door, etc.